Spring 5-1-1899

Wireless Telegraphy

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W I R E L E S S   T E L E G R A P H Y.

*** A THESIS ***

- by -

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May, 1899.

(A).- PHYSICAL THEORY.

Maxwell's theoretical deduction, as to the propagation of electric and magnetic energy by means of vibratinns of the ether, was established experimentally by Hertz in 1887. This was a culminative master stroke ending the two hundred years old problem, raised by Newton, discussed since then by almost every scientist and philosopher, who either proposed that action at a distance is the true explanation of the phenomena of the visible universe, or, who on the other side, holding action at a distance as absurd, taught the existance of an intervening medium, thus foreshadowing the greatest achievement of the nineteenth century, which forever will be known through coming generations as the "Ethereal Century". True, that only part of the Newtonian problem was solved, we know of the waves of sound, of light, of electricity, but singularly enough nothing as yet was done in the line of gravitation; we still know as little about it as the scientist of the eighteenth century, Here a set of men, following each other as Faraday, Maxwell and Hertz followed each other in theory of electricity and magnetism, are still to be expected.

Hertz's classical experiments proved the propagation of electric energy to be of a wave form, wave of some medium called ether, permeating all the substances, possessing certain physical properties and obeying certain laws. Such waves could be directed by means of metalic conductors or could be sent into space, as rays of light from an illuminating point. Further they can be reflected, polarized, refracted - just as light waves. Wave is produced every time an electric energy is created and it spreads into space from the dynamo, battery or whatever else is used for establishing an electrical disturbance.

These disturbances or waves spreading out into the space produce certain effects. Electromagnetism is the familiar instance of these. Plainly, if the waves produced will be of such nature that their effect will be far reaching and if they will be made to attack a suitable "perceiver" - a mode of signaling without wires will be the result. This is the problem of wireless telegraphy in its present stage of development, and what was achieved in that line we will expose in the following pages.

Accordingly to the results of Hertz, who differentiated the syntonized receivers or senders from well absorbing ones (the difference between the two being, that the first are persistent vibrators well adapted for picking up disturbances of precise wave length, and the others are not), a synotizing arrangement was used at first in the receivers; this considering the quality of waves used later on and the sensibility of perceiver was found more ornamental than useful and accordingly was left out from the fixtures.

There seems to be no great variety in the emitters used, as to detectors, they possess whole history of development, their action being as ingenious as anything possibly could be. Without enlarging upon these we will simply reproduce the compilation of Lodge as given in his work on "Signaling without Wires":

detectors of radiation:

(1) Physiological:
- (a) eye,
- (b) frog's leg,

(2) Chemical:
- (a) photographic plate,
- (b) explosive, gases,
- (c) photoelectric cell,

(3) Thermal:
- (a) thermopile,
- (b) bolemeter,
- (c) expanding wire,
- (d) ~~thermal~~ thermal junction,

(4) Electrical:
- (a) spark,
- (b) telephone, air gap, arc,
- (c) vacuum tube,
- (d) galvanometer,
- (e) electroscope,
- (f) trigger tube,
- (g) Mirror detec

(5) Mechanical:
  (a) electrometer,
  (b) suspended wires,

(6) Microphonic:
  (a) selenium, cell,
  (b) impulsion cell,
  (c) filings,
  (d) coherer.

But only the discussion of the most important will be given.

To make sure of the result, not a single but a series of waves are used in producing signals. For this purpose vibratory discharge is created, a discharge of rather large energy of radiation and persistently vibrating, these being two paramount conditions. Usually an induction coil terminating in two or a number of balls at suitable sparking distances from each other is used for that purpose, high frequency of oscillations being secured by means of a rapid interrupter. Action of such arrangement is plain when we consider the electricity to possess a momentum just as a material body has, and the discharge flowing from one sphere to the other resembles exactly the action of a pendulum before it comes to rest in slightly resisting medium. The coil should have knobs instead of points; feeble short sparks are ofter better exciters than strong ones and in general a crackling spark is the best, when coherer is used for receiver, since it better responds to sudden jerks than to other disturbances. No syntonizing arrangement is required for detecting such disturbances.

Strengths of waves increases with the increased area of the vobrator, accordingly a long wire is attached to one of the balls and another large capacity - usually the earth, to the other ball. The wire, if placed vertically, besides acting as capacity, serves as a radiator, its elevated position enabling it to produce more powerful effects, than the waves created below, directly at the spark gap, since piercing buildings and other obstacles thesee lower waves diminish in energy. In practice it was found necessary to use 20 feet of vertical wire to telegraph one mile, 40 feet for four miles and so on in ratio of aquares. Usually a large metallic plate is placed at the upper end of the wire, its meaning being same as that of wire itself.

It is plain that signals thus produced are of undirectional nature, or, more closely, directed everywhere in three dimensional space. Thus any number of receiving apparatus can be effected at once, eliminating all privacy of message, the number being limited only by the length of wire, which plays exactly the same part in receiving as in the transmitting instruments, i.e., any detector with wires shorter than the minimum for given distance will not respond.

In laboratory experiments and indeed in all short distance signaling, where the discharging areas are small, a certain special direction can be given to the waves by means of parabolic reflector. This is ofcourse impracticable in case of fifty or a hundred feet of vertical vertical wire, and it remains a question of future whether directing through large distance be possible. Any metal could be used for reflector, as in general a good conductor of electricity acts as a screen against the waves and vice versa. Following is the relative table of reflecting power of different substances:

Glass 0	Wood 12	Tin-foil 80
Human body...7	Tea paper...70	Sheet copper..100

Here probably lies the potentiality of future improvements, and from it also we will notice the advisability of elevated radiators - such that part of the waves can pass from transmitter to receiver unobstructed.

Arriving at the plate and the wire collector of the receiver, the waves effect in certain manner the receiving apparatus and thus the signals are recorded. Here comes into play probably the most ingenious piece of apparatus from all used in the whole process, we refer to the coherer - mentioned already by name amongst other detectors of radiation. The honor of its invention is held by Prof. Branly, of Paris, although the credit is also claimed by Prof. Onesti, of Fermo, and naturally enough Prof. Lodge comes for his share of glory by developing the originally crude tube filled with filings into that which at present is styled the coherer.

In 1890 Mr. Edward Branly found that a burnished coat of porphyrised copper, spread on a glass, dimished its resistance enormously, from some millions to some hundreds of ohms, when it was exposed in the neighborhood of Leydon jar or spark coil. He also found that a tube of metallic filings behaved similarly, and that it recovered its original resistance on shaking, after the disturbance ceased. If the filings used are coarse the tube responds very well to short distance signaling, if fine - it has a larger reange of sensibility. As found experimentally a mixture of carbon and silver, carbon and nickel or simply iron filings will do very well for short distances, silver with about 10% nickel is to be used for long distances. To prevent oxidation in the air, hydrogen atmosphere or usually a vacuum is formed in the coherer, sometimes simple heating, while sealing the ends, is sufficient, but as a rule a vacuum machine ought to be employed. As mentioned above a vertical wire and the earth are connected with the two ends of coherer, wire acting as collector of waves and the earth together with wire forming probably another oscillating arrangement as in case of transmitter, or it may be simply connected for symmetry, as it was found many times that grounding is not essential. Some ingenious persons claim that ground connection at both stations suggests action of ground currents, but this seems hardly probable. Anyway here is a fertile spot for future cultivation by scientifically inclined gentlemen.

Another "theorless" proposition is the explanation of what happens in the coherer, so as to enable it to respond to the disturbances. As its name implies it is supposed that some kind of cohesion occurs, this is Lodge's theory who christened the new apparatus. It is a modern hypothesis to explain the formation of the rain or snow flakes as the effect of atmospheric electrification. Great light was thrown on this meterological phenomena by Lord Rayleigh experiments with vertical water jets influenced by an electrode. It was found that instead of rebounding in all directions, the drops formed great globules - a regular thunder shower. Then came Lodge's famous dust experiment where an introduction of an excited stick of sealing wax into a dusty atmosphere of a room or a jar culminated at once in clearing the atmosphere, the dust falling in great masses to the bottom. Something similar happens in the modern lightning arresters after an electrical storm- but so much perhaps will be sufficient in order form a hypothesis as to the action of coherer. Suppose two clean (i.e.unoxidized) peices of metal in light contact to form a conductor between two poles of voltaic cell, a film of oxide envelops as a rule their surfaces, thus preventing the passage of current since voltage of the cell is not strong enough to break the film except may be at one or two infinitesimal points - the current thus being infinitesimally strong. Now let a slightest surging occur, say under influence of a discharge of an induction coil, the film at once breaks down, perhaps not completely - this being a question of intensity, but permanently. What has happened is a form of electrical welding, a cohesion of particles underinfluence of electrification of atmosphere.

The fact of cohesion of at least of reduction of resistance in the coherer can be demonstrated to the observer by connecting a battery and a galvanometer in series; any time after the resistance is diminished the battery can be applied and the same effect is obtained until the coherer is decohered by means of a light tap. The strength of the decohering tap is modified by the strength of disturbing source. It may be here noticed that in case of a good coherer mechanical and electrical disturbances act exactly oppositely on the coherer, one increasing the resistance and thus preventing the action of battery, the other acting exactly oppositely.

Now we can see that if a suitable key is operated in the primary of induction coil at the transmitting station a corresponding signal will be received through the coherer by the Morse relay and sounder if they be connected to the coherer circuit. Ofcourse a call bell and other latest improvements in common telegraphy could be used with advantage in this scheme.

This is the state of theory and practice of one of the most promising inventions of the closing decade of our century. Perhaps it would be only proper to mention the name of Mr. Marconi, a young Italian, who inspired by the possibility of signaling with waves, started to adapt the laboratory experiments of a physicist to the demands of business world. To his ceaseless labors are due the introduction of vertical wire, of grounding, of best form of coherer, and so on; quite a little yet might be expected of him in the future if nobody perchance possessing more ingenuity and knowledge will enter into the race.

How vast are the possibilities of this invention is needless to say. It may be the cheapest, most efficient, unaffected by any atmospherical changes means of communicating between stationary points and besides that the only practicable on a large scale signaling between moving stations, or places closed as yet to the invasions of civilization as for instance the "darkest Africa" or the "North Pole". It is highly probable that enforced by a single coherer and sparking machine a future Livingstone or Nansen will be able to accomplish what so many others before him failed to do. This is also a theme for some imaginative speculator to develop, while proposing new schemes for intercommunication between planets. And if there be a possibility of improving the instruments so that only a special transmitter will influence a special receiver the last word in the development of our "Wireless Telegraphy" will be said.

(B).-MATHEMATICAL ANALYSIS.

(1).-Lord Kelvin's Theory of Electric Oscillations.

We shall consider a conductor discharging through a conductor, q- being quantity of electricity in conductor, c- its capacity, v- the potential difference and R and L- the values of resistance and self induction of the conductor.

We have (1) $q=cv$; (2) energy $= 1/2\ vi.dt = 1/2\ vq$; since $i = dq/dt$; Now since rate of decay of energy = a rate of electric magnetic energy taken up by the conductor + a rate of energy dissipated in heat we have

(3) $d/dt\ (1/2\ qv) = d/dt\ (1/2\ Li) + Ri$;

and since $v = q/c$, $d/dt\ (1/2\ qv/c/ = q.dq/c.dt$; c being independent of the time (3) may be written as

(4) $q.dq/c.dt = Li.di/dt + Ri$;

but i as we know is dq/dt, hence

(5) $dq/dt + R/L.dq/dt + 1/Lc.q = 0$

this being our working equation.

The value of q that would satisfy (5) is $q = Ae$ --(6) where if we call $R/L = a$, $1/Lc = b$, m is determined by

(7) $m + am + b = 0$, $m = -a/2 \pm (a/4 - b)$

and according as a/4 is greater or less than b the solution will be real or imaginary.

In the first place we have

(8) $q = Ae + Be$;

denoting a discharge dying gradually away as for instance the pendulum coming to rest in a slightly resisting medium. In the second case since a complex quantity may be always written as

(9) q = Ae + Be = e (Pcos t + P sin t)
- an equation of a periodic motion showing that the discharge decreases by a series of gradually diminishing oscillations.

Plotting (8) and (9) we obtain graphical illustrations of the two cases (See Figure).

The above analysis show certain relations between resistance, capacity and self induction of circuit, the sphere of gradual diminunition of charge being divided by value of R = (4L/c) from the sphere from oscillating discharge. Now since

sin t = sin (t +) and cos t = cos (t +)

we see that = interval of time for traversing a wave length and the period T = 2 , i.e., and n = 1/T =
thus showing the wave lengths and period of waves outspreading energy.

(2).- Hertz's Treatment of Electric Oscillations According to the Maxwell Theory.

Let P and P denote the electrical and magnetic forces respectively, X,Y,Z, and being their respective components along the three axis of coordinates of cartesian system, then the following relations (1 - 4) are supposed to hold true in the Faraday-Maxwell theory for forces in free ether:

(1) C. / t = Y/ z; C. / t = Z/ x - / z;
C. / t = X/ y - Y/ x
(2)
(3)
(4)

This last relation whose left hand member is expression of energy of the system, can be deduced by the "Divergence Theorem" by multiplying (1) and (2) by and X,Y,Z, respectively, adding and integrating all over the surface of which is element of volume and - the surface element, and where n is normal to that surface.

In finding solutions of these four equations, we will consider only the special case where the forces are in meridian plane passing through axis of z and are symmetrical with regard to z, i.e. depend only upon value of z coordinate and the distance of point of application of this force from z axis, which distance we will call , where evidently = (x + y)

Calling R- the component of P along and P- the component of P perpendicular to meridian plane, so that R = X.x/ + Y.y/ and P = , we will prove that the following system furnishes a solution to our differential equations under the specified conditions.

(5)
where (6) satisfies the equation
(7)

From (5) and (6) we get z = 1/ .Q/
z being thus expressed in cylindrical coordinates, which reduced to cartesian system give Z = Further since x / and y/ = , we have X = R. , Y = , from which by comparing with (5) and (6) , and rewriting the value of Z we obtain
(8)
and in similar manner for magnetic forces we obtain from (5) and (6) ----(9)

Now substituting these values into our equation (1 - 4) we find them identically satisfied, hence (8) and (9) are evidently solutions of our original equation limited by certain above named conditions.

So much about our working equations, now we will proceed with the discussion of forces caused by rectilinear oscillations. Assume (10)
where E = quantity of electricity, l = length, m = , n = /T. if we assume m/n = T/ = A, such value of satisfies equation (7) at all points except the origin.

To discuss the condition at the origin we will describe by the distance of a point from the origin, so that = r.sin and z = r. cos , being the angle between and r. For r vanishing by the value of as given in (10) will evidently reduce to
(11)
and since r = (x + y + z); (12)
and consequently by applying this to (8) and rewriting the values of X and Y we get
(13)
Thus we see that the components of X, Y, Z, are derivatives of which is the potential = = d / dz = - El.sin nt(1/r) (14)
now can be regarded as potential of a double point, where E is its strength, z - its axis, T - its period and -E.l and + El the limits of oscillation of its moment. Hence the solution of our original equations represents the distribution of force producing a rectilinear oscillation, and further as from (14) we get according to Faraday's law of E.M.F.
(15)
the force of current element oscillates also between values + and - A E.l/T according to Biot-Savart law.

At some distance from origin is given by (10) and consequently (16)
from which by means of relations (5) we obtain the values for z, R and P. So obtained expressions would be too complicated to deal with, moreover they are not necessary for our investigation, hence we will consider only special cases enough to enable us to draw our conclusions.

First take forces in direction of oscillation, i.e., in the axis of Z. In this case we have
by means of which we obtain from (5) and (16)
(17)
This shows that the electric force acts always in direction of oscillations, and that at small distances it diminishes inversely as cube and at larger distances inversely as squares of the distance.

Next we will analyze the forces in the xy plane. Here
by means of which we obtain from relations (5) and (6)
(18)
This shows that the force is parallel to oscillations, it diminishes with increasing distance rapidly at first, then very slowly. Hence comparing with the previous case we may conclude that at longer distances the action is observable in equatorial plane and not along axis of oscillations. The amplitude = 1/r.El (1)

In the third place we will analyze forces at very great distances. Here the higher powers of 1/r may be neglected in comparison with lower ones. Hence (10) reduces to

from which we obtain by relation (5)
(19)
We will notice that here Z.cos + R.sin = 0. Hence at great distances the force is everywhere perpendicular to r, and the propagation of force of a transversal wave. The amplitude = Elm.sin( ) at a constant distance from zero point it decreases toward the axis being proportional to the distance from the laster,
(13) and (15) then (17), (18) and (19) give us the state of conditions in four special cases. For all the remaining points we may represent the distribution of forces graphically by drawing

curves Q = constant, for times t = 0, 1/4T, 2/4T, 3/4T ---- n/4T, This is comparatively an easy task since Q is product of two independent factors. Thus we split Q into two factors and determine for which sin is = to one factor, then by means of auxillary curve the value of r such that its function as contained in Q give the otherfactor. In consequence we obtain a set of curves as given in figure . They illustrate the distribution of force for times 0, 1/4T, 2/4T --- and hence for all other multiples of T/4- thus we get the representation of electrical waves.

For the explanation of the curves we quote from Hertz:

" Let us begin our explanation of the diagram with Fig.27. " Here t = 0; the current is at its maximum strength, but the poles " of the rectilinear oscillator are not charged with electricity- " no lines of force converge towards them. But from the time " t = 0 onwards, such linesof force begin to shoot out from the " poles; they are comprised within a sphere represented by value " Q = 0. The velocity with which this vertical surface Q = 0 " spreads out from the origin is at first greater than 1/A; in " fact, for the value 1/4.T, this latter velocity would only cor- " respond to the value of 1/4. given in the figure. In the sense " of our theory we represent the phenomenon by saying that the waves " which are being developed do not owe their formation solely to " processes at the origin, but arise out of the conditions of the " whole surrounding space, which latter, according to our theory " is the true seat of energy. However this may be, the surface " Q = 0 spreads out further with a velocity which gradually sinks " to 1/A, and by the time t = 1/2.T (Fig.29) fills the space R. " At this time the electrostatic charge of the poles is at its " greatest development; the number of linesof force which converge " towards the poles is a maximum. As time progresses further no " fresh lines of force proceed from the poles, but the existing " ones rather begin to retreat towards the oscillating conductor, " to disappear there as lines of electric force, but converting " the energy into magnetic energy. The number of receiving lines " of forse is just as great as the number which proceeded out- " wards, but their energy is necessarily diminished by the energy " of the parts detached, this loss of energy corresponds to the " radiation into space, this being shown by Fig. 30. In Fig.27 - " to which we return for the time t = T, conceiving the arrows to " be reversed - the detachedportions of the lines of force fill " the spherical space R, while the lines of force proceeding from " the poles have completely disappeared. But new lines of force " burst out from the poles and crowd together the lines whose devel- " ment we have followed into the space R (Fig.28). These lines " runmore and more into a pure transverse wave motion, and as such " lose themselves in the distance."

APPARATUS.

(I) SENDING APPARATUS.

Sending apparatus consists primarily of a cascade of brass balls, so arranged as to produce a disruptive discharge between them and to excite the greatest number of ether vibrations. To effect this, arrangement shown in figure 1 was used. It consists of a train or cascade of four brass balls so arranged that the discharge takes place successively between each ball.

The relative distance between each ball is adjustable as the length of the air gap between each ball must be varied so as to produce a white, sharp, continuous discharge with given E.M.F. in primary of induction coil. With an E.M.F. of fifty volts in the primary of a coil giving a ten cm. spark the air gap between balls (1) and (2) was about one cm., that between (3) and (4) about 5 cm. With a higher E.M.F. these distances may be increased but never should they be so great as to make the discharge of a "buzzy" fuzzy nature as this kind of a spark was found not to be so effective as a short and more disruptive one. The best results were obtained with white, sharp discharges accompanied with a crackling sound. Balls (3) and (4) are four inches in diameter and were placed in a highly insulated box, as shown, intended to be filled with vasaline oil, the object of which was to produce a more uniform discharge. Marconi in his earlier experiments insisted upon the use of this dialectric but more recent investigation has shown it to be of no practical value and to seriously interfere with the free radiation of the electric waves. It was not used in any of the experiments.

All supports of a transmitting apparatus must be thoroughly boiled in parafine oil and otherwise insulated to prevent any leakage.

(II) REFLECTORS.

For short distances the waves may be reflected in parallel beams by means of metallic parabolic reflectors. The transmitting apparatus was placed in a focal line, thus reflecting the waves in any desired direction. For this purpose a large parobolic reflector was made of tin-foil, and although it was shown that the tinfoil did not reflect all the waves it was successfully used up to distances of 100 feet. The focal distance of this reflector was four inches.

(III) WEHNELT INTERRUPTER.

In the primary of the induction coil a Wehnelt Interrupter of the usual type was used. In a glass tube 8 to 10 cm. long and 2 to 3 mm. internal diameter a platinum wire was sealed and filled with mercury into which the positive terminal of the battery was inserted making the platinum point the anode of the cell. The negative terminal was attached to a small piece of lead plate two inches square and the whole immersed in a 10% solution of sulphuric acid, the lead plate being the cathode of the cell. Care must be taken to keep the terminal separated.

After standing some time the cell was found to become fatigued and a precipitate of lead oxide formed in the bottom. To restore the cell a new solution may be made or the mercury may be poured out of the tube and a platinum heated to redness, after which the cell will work. This devise was used exclusively and gave excellent results.

An ordinary telegraphic key was placed in the primary circuit. By this means short or long distance signals may be made as in the Morse system.

(IV) VERTICAL CONDENSER.

For long distance transmission a vertical condenser was used. This consisted of a No.10 insulated wire about 30 feet in length to the top of which was connected a zinc plate three feet by three and one-half feet, the whole acting as a capacity. One side of the transmitter is connected with the lower end of the vertical wire and the other side is grounded as shown in diagram of connections.

The function of thus connecting large capacities to both sides of the transmitter is to increase the wave length and also the intensity and effectiveness of the discharge, the result being similar in effect to that produced in sound waves by means of a resonator.

The method of suspension of the vertical wire is immaterial, excepting that care should be taken that no part of it is grounded, if suspended from a brick or stone building neither the wire nor plate should touch any part of the building.

(V) RECEIVING APPARATUS.

Figure 2 shows a cross-section of a sensitive coherer. The first coherer made No. 1 was used in the preliminary experiments and consisted of a small glass tube filled with iron filings into which two wires were inserted and the ends sealed with wax. A coherer of this crude form worked fairly well for distances up to thirty feet.

Coherers Nos. 2 and 3 were made in the general form of the more sensitive ones, excepting that copper plugs were soldered to to fine copper wire and sealed in the tube with wax, the distance varying from two to five mm. between plugs, depending on the internal diameter of the tube, and silver filings mixed with about fifty per cent coarse carbon filings instead of iron filings. Coherers of this type are much more easily made than the more delicate ones used for long distance transmission and for general laboratory experiments give good results. It was found that for short distances the mixing of the carbon filings with the silver filings in the ration of one to one gave more satisfactory results than the more sensitive combination of silver-nickel, the advantage being that the instrument is more easily decohered and having a higher resistance the effect is much more pronounced. The carbon-silver coherer gave excellent results for distances over 100 feet.

Long Distance Coherers.- To make a highly sensitive coherer suitable for long distance transmission two silver plugs each three to four mm. in length and two to three mm. in diameter are first soldered securely to two separate peises of platinum wire each 8 to 10 cm. in length, after which all acid or flux used in soldering must be thoroughly washed off and the ends of plugs carefully polished. A small glass tube two to three mm. internal diameter and four to six cm. long is then carefully cleaned and dried. Any moisture whatever in the tube will destroy the sensitiveness of the instrument. One of the silver plugs is then placed about midway in the tube and the platinum wire securely sealed in place aft r which a small quantity of silver filings mixed with 10 to 20 per cent nickel filings is put in as shown in cross-section. The filings must be clean and dry and free from grease. A rather coarse file should be used in making them in preference to a fine one. The second plug is then inserted and similarly sealed in place as shown. Both plugs must fit tightly to prevent the filings from sifting through. It was found to be advantageous to make the plugs slightly less in diameter than that of the tube and then to wrap them with thin soft paper after which they were forced into the tube thus fixing them in place and also preventing any displacement of the filings. Care must be taken however not to have the paper cover the end of the plug and thus prevent thorough contact with filings. The sensitiveness of the coherer is greatly increased if the ends of the plugs are slightly amalgamated before inserting them. Great care must be taken however as a very slight excess of mercury will spread throughout the filings and ruin the coherer. A globule the size of a pin point will often be found excessive. After amalgamating all particles not closely adhering should be wiped off. To make a highly sensitive instrument five per cent metallic uranium may be added to the silver-nickel filings. Those made without it however were found to be very sensitive and gave good results. The plugs must not press tightly against the filings and in all positions of the coherer the filings should be loose enough to be thoroughly shaken when slightly tapped. In sealing in plugs care must be taken not to oxidize the silver by using too hot a flame. In sealing in the second plug however the tube must be thoroughly warm and as high a vacuum as possible obtained. In all cases a partial vacuum is essential. In making these for long distances it was found necessary to connect the tube to air pump and a vacuum of not less than 1/20 of an atmosphere secured before sealing. In coherers of above dimension the distance between plugs must not exceed two and one-half mm.

In those made the distance varied between one and two mm. To keep the coherer sensitive a large circuit should never be allowed to pass through it. Marconi says thatnot more than one mm.ampere, but two to three mm.ampheres was found not to materially injure the instrument, No more than one LeClanche cell should be used in coherer circuit unless additional resistence is put in series.

(VI) SYNTONIZING PLATES.

For short distances syntonizing plates may be attached to the coherer as shown by dotted lines in Fig. 3. The length of these plates may be determined by pasting a strip of tin-foil 50 to 60 cm. long on a glass plate and then dividing it in the middle by cutting across with a sharp knife. When this is placed near the transmitter electric discharges take place across the slit. The length of each strip is gradually diminished until a maximim discharge takes place when held two to three meters from the transmitter. This will be the length of the plates allowing for the length of wire in coherer tube which is to be deducted from the original length as determined above. The usefulness of syntonizing plates has been disputed but in the experiments performed a much better effect was obtained by using them.

(VII) OTHER APPARATUS.

In the coherer circuit a sensitive relay closes the local circuit, which may be used to work a decoherer, consisting of a small hammer to tap the coherer by means of an electro-magnet, and also to work a sounder or other instrument for recording the signals received.

By rigidly fastening the sounder to the upright supporting the coherer the action of the sounder may be made to take the place of a decoherer, the jar of the sounder being sifficient to break the bond of cohesion.

Instead of the coherer circuit closing the relay of the local sounding circuit as shown in diagram a telephone receiver may be placed in coherer circuit and the action of the waves on the metallic particles of the coherer distinctly heard.

(D).- DESCRIPTION OF EXPERIMENTS.

No definite telegraphic or other messages were attempted. The efforts were said to be successful when the coherer was effected by the waves at an instant determined by the second hand of a watch when such waves were known to exist the evidence being the click of the Morse receiver or the humming sound in a telephonic receiver or the deflection of a galvanometer.

Ground Connections.- In order to avoid the labor of digging, ground connections were made by brightening the surface of water or steam pipes and attaching wires to them so that a good electrical connection existed between one terminal of a sparking transmitter or coherer and the ground. It may be said that with such grounding, there would exist a metallic connection through the earth between the transmitter and receiver. It is doubtful however if whatever current there was followed such a metallic connection more than a good conducting stratum of earth, and if not, the test is not unfair.

Experiment No.1.(Distance 100 feet, Mar.31,1899.)

The experiment was performed in the physical laboratory of the Hale Scientific Building. No vertical wires were used and no ground connections made. Primarily syntonizing plates were connected in series with the coherer, a LeClanche cell and d'Arsonval galvanometer, which apparatus constituted the receiver. Both the coherer and the transmitter were horizontal. With the receiver t duction coil was closed and as sparks passed between the brass spheres of the transmitter, immediately a positive deflection of the galvanometer in the coherer circuit was noticed. This deflection was maintained permanently until the coherer was tapped quite strongly, when the galvanometer came back to the zero position. Distances of 50 and 80 feet were tried in like manner and it was found that at 80 the galvanometer was just effected.

Second coherer was then tried and by experimentation similar to the above slightly better results were obtained, There was a slight deflection of the galvanometer at 100 feet, and this being the limits of the laboratory no greater distance was tried.

Experiment No. 2.(Distance 300 feet, April 15,1899.)

This was the first outdoor test and was performed between the Hale and Main Buildings at the University campus. From the third story window of the Hale Building an insulated No.12 copper wire was suspended vertically from an insulated support, so as to clear the outer wall some two feet, the lower end of which wire was connected to one terminal of the sparking transmitter. The other terminal of the transmitter was connected with the earth by means of a water pipe in the building.

From the third story of the Main building some 300 feet away, a wire was suspended in a manner similar to that of the transmitting station, one terminal of the coherer being attached to the lower end, the other terminal being grounded to a steam pipe within the Main building. The vertical wires at each building were about thirty-two feet in length. The coherer used was one of the sensitive ones. On sending a signal a distinct and positive movement of the armature of the relay magnet was noticed by the experimenters and it was followed by distinct sound produced by the Morse sounder. In this experiment both the sparking transmitter and the coherer were horizontal.

Experiment No. 3.-(Distance 1200 feet, April 15,1899.)

Leaving the apparatus set up as in experiment No.2 at the transmitting station, the receiving station was moved to the engineering building and the receiving apparatus was set up precisely as in experiment No.2. The vertical wire in this experiment was about 27 feet long and suspended as before. Signals were received equally as well at this distance as in experiment No.2.

In order to make sure that the signals received corresponded to the making of the primary circuit of the induction coil at the Hale Building, the following devise was used: The Hale building being connected by means of wires with the storage battery in the engineering building, the telegraphic key which hadserved to make and break the primary circuit of the induction coil at the Hale building was placed in the other end of the atorage battery circuit at the engineering building, at a point some 50 feet away from the receiving apparatus. In short the circuit of the primary of the coil was made and broken at another point and that point was near the receiving station where it could be easily ascertained w whether the clicks of the receiving instrument corresponded with the make of the transmitting circuit. It was found that the two events, namely the "make, and the "click" were simultaneous.

Experiment No.4.(Distance 1 and 1/2 miles, April 21,1899.)

On April 20th, a receiving station was set up at the Colorado Sanitarium, a three story brick building backed afew hundred feet in the rear by foot-hills of the Rocky Mountains which rise to a height of some 500 to 1000 feet a short distance to the North-west. The apparatus transmitting waves was placed in a window of the Hale building as before. All apparatus was the same as that used in experiments 2 and 3, except that at the top of the vertical wire at each station, and connected with the wire by means of solder, was placed a zinc plate three by four feet and one mm. thick.

The vertical wire at the Hale Building was about forty feet long, at Sanitarium it was about fifty feet long with a vertical part of about forty feet, the other ten feet being horizontal, the zinc plate at the Sanitarium was placed very near the building but was insulated from it by its wooden frame.

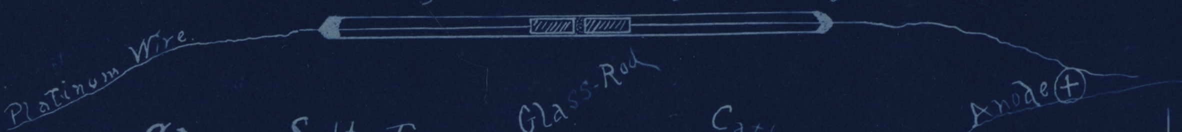
A sensitive coherer (No.3) was tried and no results obtained.

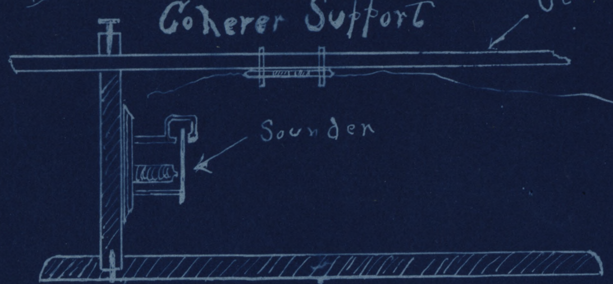
On April 21, a more sensitive coherer was used and also a new and larger relay of resistance of about 150 ohms instead of the one used before. Man stationed at the Hale building was instructed to send signals at intervals of ten seconds for five minutes. Every signal was received at the Sanitarium and in almost perfect time. The ground connection at the Sanitarium was then broken and the experiment repeated. No results were obtained.

Previously both ground connections had been made to water pipes. A new ground was now tried by connecting to an iron rod driven about one foot into the lawn of the Sanitarium. The signals were now received as well as before.

A small telephone receiver was placed in series with the cell and coherer instead of the relay. On repeating the experiment every signal was heard in the telephone with perfect distinctness and exactly on time. In experiment No.4, no extra resistance was placed in the coherer's circuit.

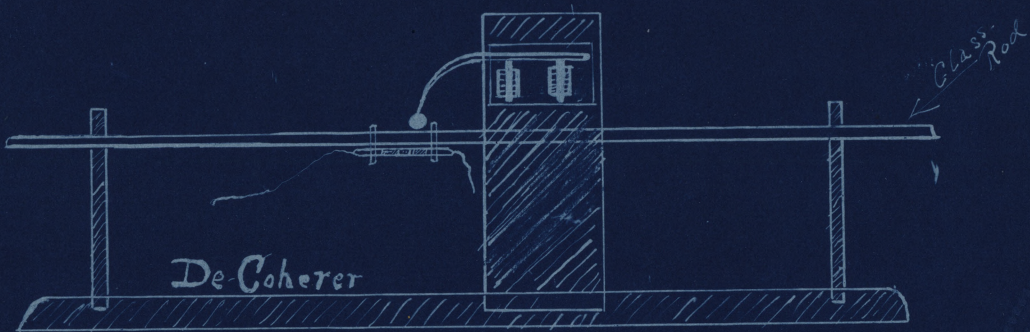
Fig II





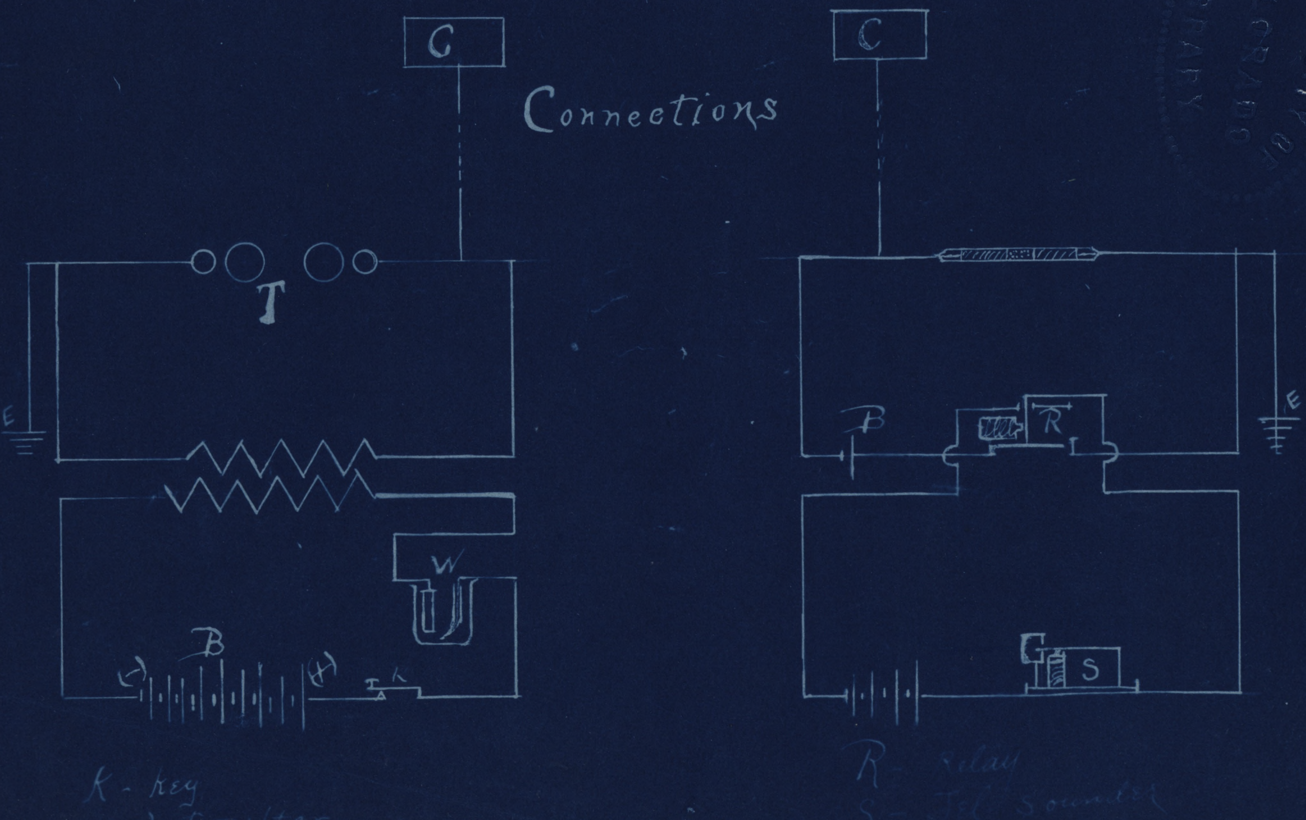
Coherer Support

Wehnelt-Interrupter



De-Coherer

Connections



K - key
W - Interrupter

R - Relay
S - Tel. Sounder